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TECHNICAL REPORT NO. 70-30

EVALUATION OF THE VERTICAL LONG-PERIOD SEISMOMETER, SPRENGNETHER MODEL S-5100V

TELEDYNE GEOTECH

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EVALUATION OF THE VERTICAL LONG-PERIOD SEISMOMETER, SPRENGNETHER MODEL S-5100V

by

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Sponsored by

Advanced Research Projects Agency
Nuclear Test Detection Office
ARPA Order No. 624

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14 September 1970

CONTENTS

		Page
	ABSTRACT	
1.	INTRODUCTION	1
	1.1 Purpose	1
	1.2 Authority	1
2.	DESCRIPTION OF SEISMOMETER	1
3.	SEISMOMETER TESTS AND RESULTS	7
	3.1 Assembly and adjustment	7
	3.2 Period vs mass position	7
	3.3 Mass position vs temperature	8
	3.4 Shake table tests	8
	3.4.1 Sensitivity vs mass position	8
	3.4.2 Spurious resonances	11
	3.5 Air damping	11
	3.6 Specified parameters	11
	3.7 Capacitance transducer	18
4.	OPERATIONAL TESTS	21
	4.1 Description of system	21
	4.2 Results	21
5.	DISCUSSION AND CONCLUSIONS	29
6.	ACKNOWLEDGEMENTS	30

ILLUSTRATIONS

Figure		Page
1	Vertical Long-Period Seismometer, Sprengnether Model S-5100V, without dust cover, front 3/4 view	2
2	Vertical Long-Period Seismometer, Sprengnether Model S-5100V, without dust cover, rear 3/4 view	3
3	Vertical Long-Period Seismometer, Sprengnether Model S-5100V, with dust cover in place	4
4	Schematic diagram of circuit used with differential capacitance (displacement) transducer	6
5 through 11	Free period vs mass position plots for Long-Period Seismometer, Sprengnether Model S-5100V, serial number 3680, under several conditions of operation	9
12	Mass position vs temperature for Long-Period Seismometer, Sprengnether Model S-5100V, serial number 3680	10
13	Data coil No. 1 output vs mass position for 1 Hz constant amplitude excitation	12
14	Data coil No. 2 output vs mass position for 1 Hz constant amplitude excitation	13
15	Series data coil output vs mass position for 1 Hz constant amplitude excitation	14
16	Data coil No. 1 output vs mass position for 0.05 Hz constant amplitude excitation	15
17	Data coil No. 2 output vs mass position for 0.05 Hz constant amplitude excitation	16
18	Series data coil output vs mass position for 0.05 Hz constant amplitude excitation	17
19	Linearity of capacitive transducer and detector, Sprengnether Models VCT-203 and VCT-201	19
20	Frequency response of long-period seismograph with capacitive transducer	20
21	Frequency responses of seismographs used during operational tests	22
22	Recording during quiet period, Geotech sealed	23/24

ILLUSTRATIONS, Continued

Figure		Page
23	Recording during transitional period, Geotech sealed	25/26
24	Recording during noisy period, Geotech sealed	27/28

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TABLES

Table		Page
1	Comparison of published and measured parameters for Vertical Long-Period Seismometer, Sprengnether Model S-5100V, Serial No. 3680	11

ABSTRACT

The Sprengnether Model S-5100V seismometer, equipped with both electromagnetic and capacitive transducers, was assembled and tested in the laboratory and in a vault. Data concerning its measured performance characteristics were collected and evaluated.

EVALUATION OF THE VERTICAL LONG-PERIOD SEISMOMETER, SPRENGNETHER MODEL S-5100V

1. INTRODUCTION

1.1 PURPOSE

This report presents the evaluation of a Vertical Long-Period (LP) Seismometer, Sprengnether Model S-5100V, as an instrument which offers a potential improvement in the performance of observatory seismograph systems. Included are descriptions of tests conducted and discussions of the results obtained.

1.2 AUTHORITY

All work was performed under the authorization of Task b of Contract F33657-70-C-0733, and with the prior approval of the Project Officer.

2. DESCRIPTION OF SEISMOMETER

The Vertical LP Seismometer, Sprengnether Model S-5100V, uses a spring-mass combination arranged in a LaCoste configuration and built upon a frame made of cast and machined aluminum sections. Figures 1 through 3 show views of the instrument with and without its cover. The majority of the instrument's inertial mass is concentrated in two blocks of brass mounted near the end of an aluminum boom. Smaller portions of the inertial mass are distributed along the boom, and are contributed by such items as the boom itself, the calibration coil, and the signal coils. The boom is restrained to turn about an axis determined by cross-flexure hinges made of flat metal strips that are clamped between metal blocks. Restoring force is provided by a helical spring, which is prestressed to give it a zero length, and is suspended by circular cross-section wires at both ends. Two moving-coil electromagnetic transducers convert mass movements into electrical energy and produce output voltages proportional to mass velocity. They are electrically isolated and can be used separately or can be connected in a variety of configurations. A third moving coil transducer serves as a calibrator and applies forces to the movable boom proportional to currents passed through the coil. Several mechanical adjustments are provided to permit manual adjustment of free period, mass position, and the constancy of free period as mass position is varied. The mass position can also be remotely adjusted by a motor which is fastened to the boom and, when energized, moves a small weight along the boom. A pointer on the boom and a scale on the frame roughly indicate mass position.

Small mass displacements are sensed by a differential capacitor whose outer plates are connected to the instrument frame and whose center plate is connected to the boom. Conversion of mass displacement into electrical voltage

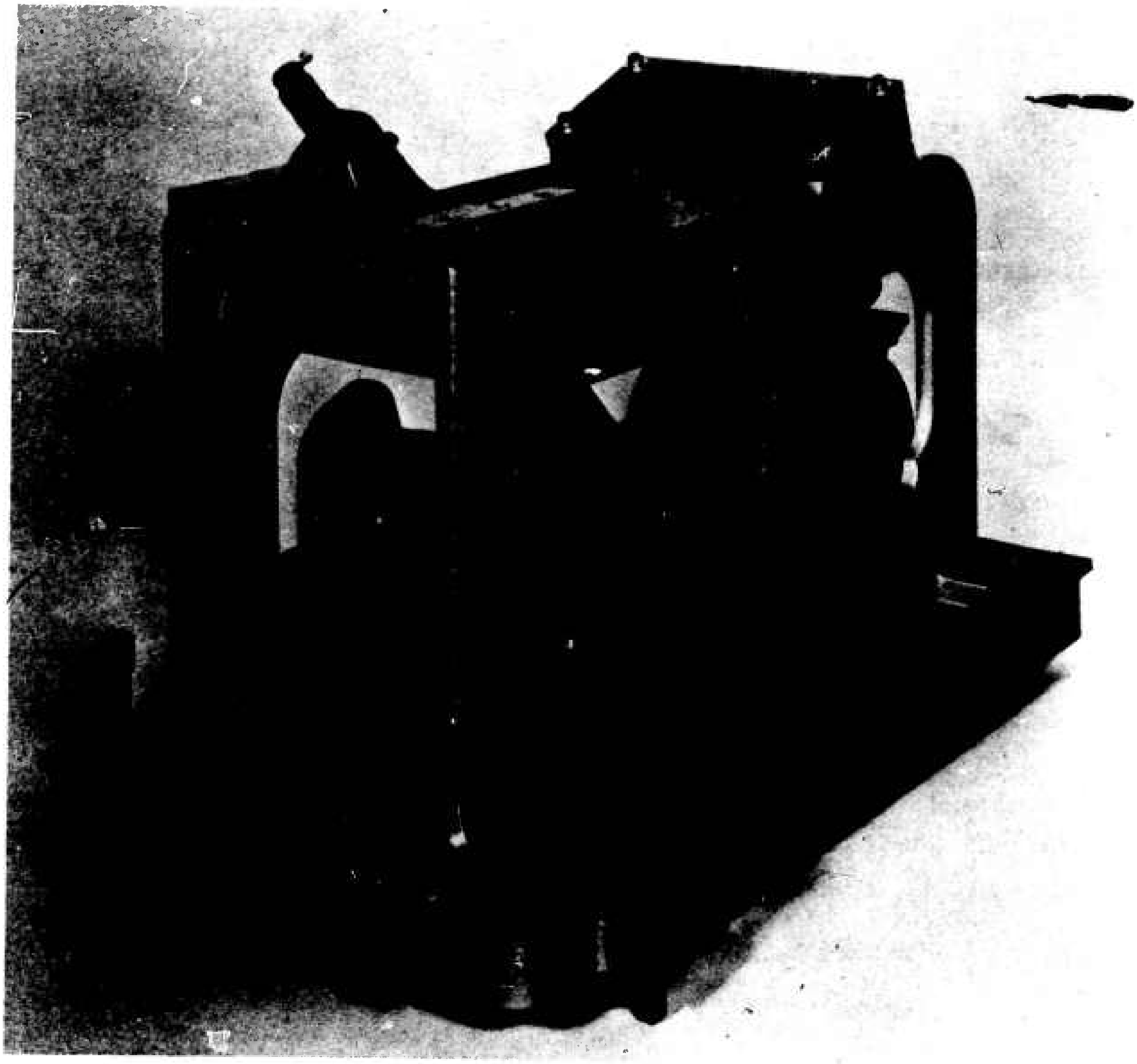

Figure 1. Vertical Long-Period Seismometer, Sprengnether Model S-5100V, without dust cover, front 3/4 view

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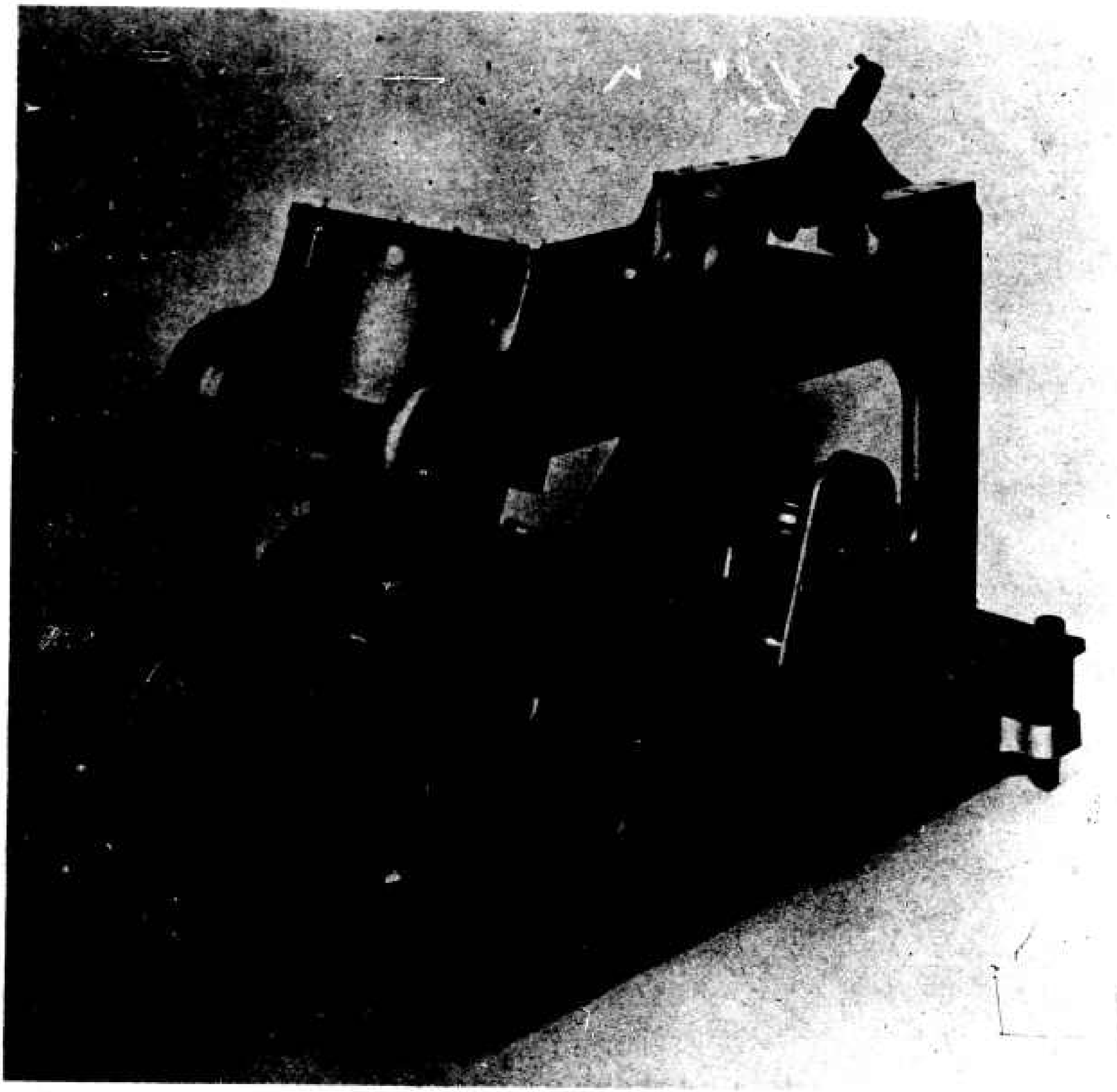


Figure 2. Vertical Long-Period Seismometer, Sprengnether Model S-5100V, without dust cover, rear 3/4 view

G 6043

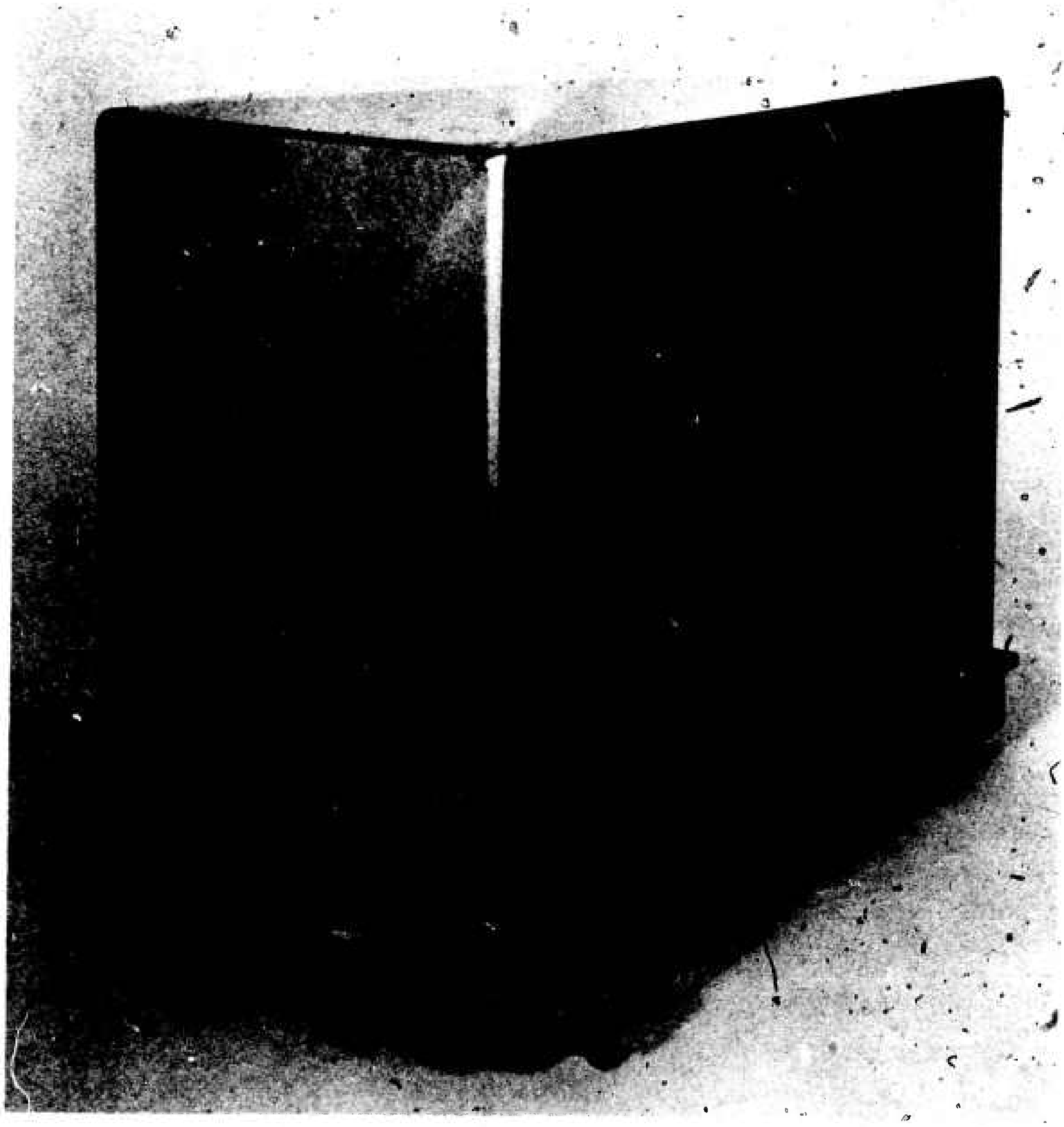


Figure 3. Vertical Long-Period Seismometer, Sprengnether Model S-5100V, with dust cover in place

G 6044

is accomplished by the electronic circuit shown in figure 4. It uses a fixed frequency oscillator and a tuned discriminator to produce a voltage proportional to mass displacement. The differential capacitor is used to tune the discriminator.

A sheet steel cover, separated from the base by a rubber gasket and secured to it by clamps, protects the instrument assemblies from dust, but provides no barrier to atmospheric pressure changes. A window at one end of the cover permits the mass-position scale and pointer to be viewed when the cover is in place.

Manufacturer's published specifications for the seismometer are as follows:

Period range:	6-40 seconds, adjustable
Mass of	
Moving systems:	11.0 kg
Spring:	0.68 kg
Distance, hinge to	
Center of mass:	32.2 cm
Center of oscillation:	35.8 cm
Center of signal coils:	34.8 cm
Center of calibration coil:	24.2 cm
Signal coils (2):	500 ohms 89 volts/m/sec
Calibration coil (1):	68 ohms 5 newtons/amp
Variation of constant with boom position	
Natural period (at 20 seconds)	5% (±11 mm) 2% (±5 mm)
Coil constants:	3% (±11 mm) 1% (±5 mm)
Spring resonance frequency:	above 20 Hz
Dimensions:	24" (L) x 13" (W) x 18" (H)
Net weight:	approx. 100 lbs.
Shipping weight:	approx. 180 lbs.

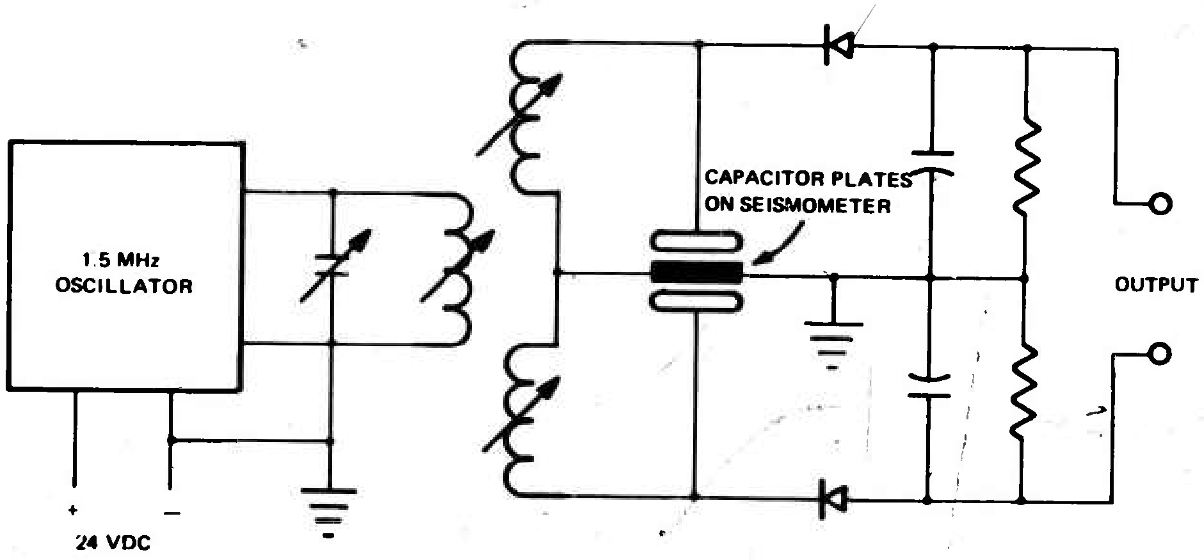


Figure 4. Schematic diagram of circuit used with differential capacitance (displacement) transducer

3. SEISMOMETER TESTS AND RESULTS

3.1 ASSEMBLY AND ADJUSTMENT

The seismometer on which all tests were conducted was identified with manufacturer's serial no. 3680. This was delivered to our laboratory in the wooden shipping crate supplied by the manufacturer. The seismometer was bolted to the bottom of the crate and was shipped assembled except for the helical spring, the two inertial weights, and the signal coil magnet assembly which were secured to the crate lid either directly or after being packed in a cardboard carton. Pins and clamps had been installed to prevent the boom assembly from moving and damaging the seismometer during shipment.

Following the instructions given in the manual furnished, the seismometer was unpacked and set up on a pier in a concrete vault located approximately 10 feet below the floor of our laboratory in Garland, Texas, Although the seismometer was handled carefully and the wooden crate showed no damage nor other signs of rough handling, one flexure was found kinked and unusable. This was replaced with a spare included in the shipment and presented no further problems. The assembly instructions were adequate, the parts were easy to identify, and all parts fit well. In particular, it was noted that the signal coil magnet assembly was well-designed. Its guide rods insured correct installation and prevented damage to the signal coils during installation.

During instrument setup one component failed. The screw threads in the suspension clamp ring that holds the upper helical spring suspension sheared out. This was replaced with a spare unit and no further difficulty was experienced.

3.2 PERIOD VS MASS POSITION

The relationship between seismometer free period and mass position was measured under several sets of operating conditions and parameter adjustments. Each set of measurements was made using the following procedure:

a. The mass position was set to zero by manually sliding the trim weights along the boom for a coarse adjustment, and moving the remotely-controlled, motor-driven weight for the final adjustment.

b. The free period was determined, and reset if required. All measurements were made by timing the zero crossings of the amplified signal coil output when the mass was swinging freely through an amplitude of 100 microns p-p.

c. In a similar manner, free periods were determined at each mass position from 10 mm below center to 10 mm above center in increments of 2 mm.

The first measurements of free periods vs mass position were made just after the unit was assembled, before any adjustments were made, and with the free period at zero mass position set to approximately 25 seconds. Figure 5 shows the results of these measurements. Note that the period lengthens with downward

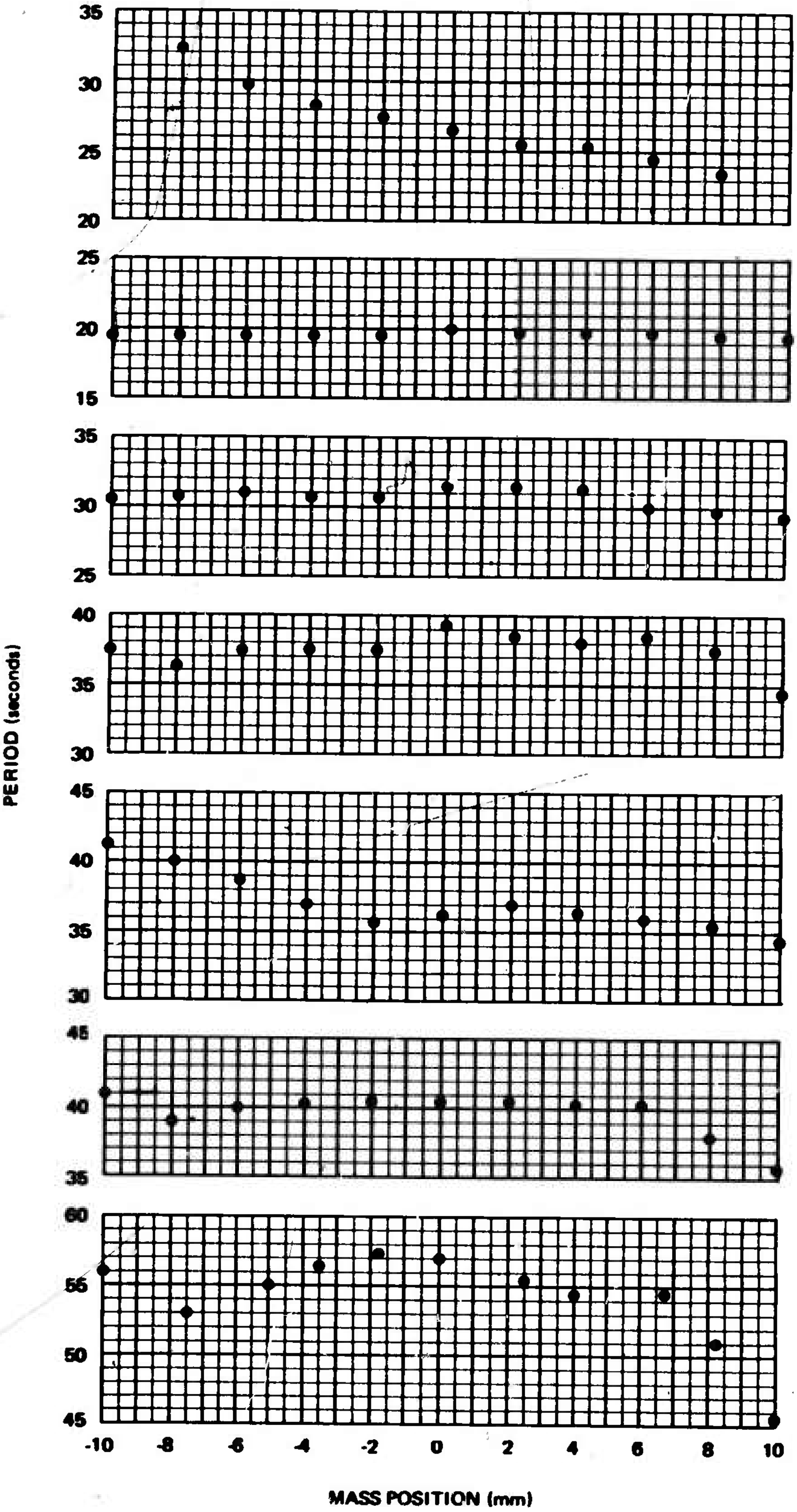


Figure 5. As initially assembled but not adjusted

Figure 6. For period of 20 seconds

Figure 7. For period of 30 seconds

Figure 8. For period of 40 seconds

Figure 9. With data magnets removed

Figure 10. With data magnets and calibration coils removed

Figure 11. With data magnets and calibration coils removed

Figures 5-11. Free period vs mass position plots for Long-Period Seismometer, Sprengnether Model S-5100V, serial No. 3680, under several conditions of operation G 6046 deflections and shortens with upward deflections of the mass, and that the change is large. This is typical of an unadjusted seismometer and indicates that its performance will be unstable and that its characteristics will vary as a function of mass position. The period vs mass position curve for an ideal seismometer would be a horizontal straight line; the curve for a good, practical instrument is symmetrical about zero mass position and droops very slightly from zero to the scale end. All the data that follow were taken after the seismometer was adjusted to produce the flattest and most symmetrical period vs mass position curve.

Figures 6, 7, and 8 show period vs mass position curves, respectively, for periods of approximately 20 seconds, 30 seconds, and approximately 40 seconds - the longest period at which reasonably stable operation could be achieved. Note how closely the T = 20 sec curve approaches a horizontal straight line whereas the T = 40 sec curve deviates erratically from a straight line. As such data irregularities could be caused by magnetic impurities in the assemblies which enter and leave the concentrated fields within the magnetic assemblies, the tests were rerun with the data magnets removed, and mass positions were observed through the window of the dust cover. The test results, plotted in figure 9, indicated a greater data irregularity with the data magnets removed than with them in place and raised a question about the data validity. However, retesting, both with and without the data magnets in place, confirmed the validity of the data. The period vs mass position curve was made considerably smoother, as shown in figure 10, by removing the calibration coil from its magnetic assembly, but leaving it on the boom to preserve the operational value of inertial mass. In view of this profound improvement, the period was reset to 56 seconds, the highest value at which reasonably stable operation was obtained, and the data shown in figure 11 were taken.

3.3 MASS POSITION VS TEMPERATURE

The seismometer was set upon a pier in our environmental test laboratory for temperature tests. A temperature-controllable chamber was installed over the seismometer, and thermistor temperature-sensing probes were placed at several points inside and outside of the seismometer. When rough checks showed that the mass moved over its entire 20 mm range with temperature changes of less than 10°F, use of temperature control on the chamber was abandoned, and instead, the overall room temperature was controlled. Several sets of readings were taken over a period of five days and are shown plotted in figure 12. The linear relation between temperature and mass position, determined by the method of least squares, has a slope of 3.02 mm per °F and an intercept of 71.8°F.

3.4 SHAKE TABLE TESTS

3.4.1 Sensitivity vs Mass Position

Linearity data were obtained by driving the seismometer at a constant frequency and constant amplitude with a Model 17736 vertical shake table, and recording its amplified and filtered output on a Model 320 recorder. Outputs from each data coil and from the two in series were recorded at each of two frequencies,

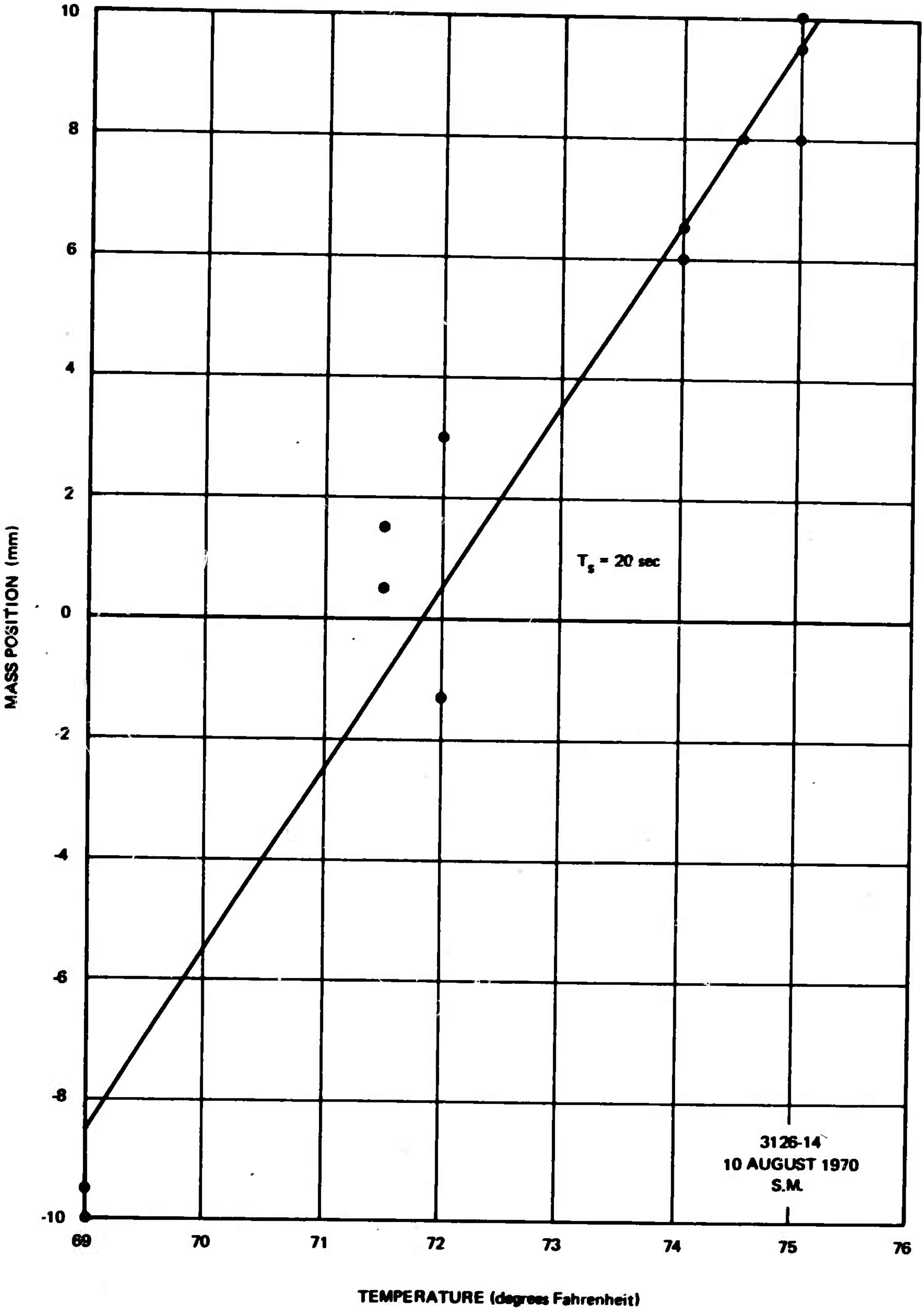


Figure 12. Mass position vs temperature for Long-Period Seismometer, Sprengnether Model S-5100V, serial number 3680

G 6047

1.0 Hz, and 0.05 Hz. The 1.0 Hz data show how transducer sensitivity varies with mass position and the 0.05 Hz data show how performance of the seismograph is affected by mass position. Figures 13 through 18 show the results of these tests and schematic diagrams of the test instrumentation.

3.4.2 Spurious Resonances

Spurious resonances were detected at 18.4, 21.3, 60, and 100 Hz by driving the seismometer with the vertical shake table and observing peaks in its output voltage. It was also noted that the helical spring would oscillate in a rotational mode about its longitudinal axis at a frequency of 2 Hz. The oscillatory system had very low losses and continued to oscillate for tens of minutes after being manually started.

3.5 AIR DAMPING

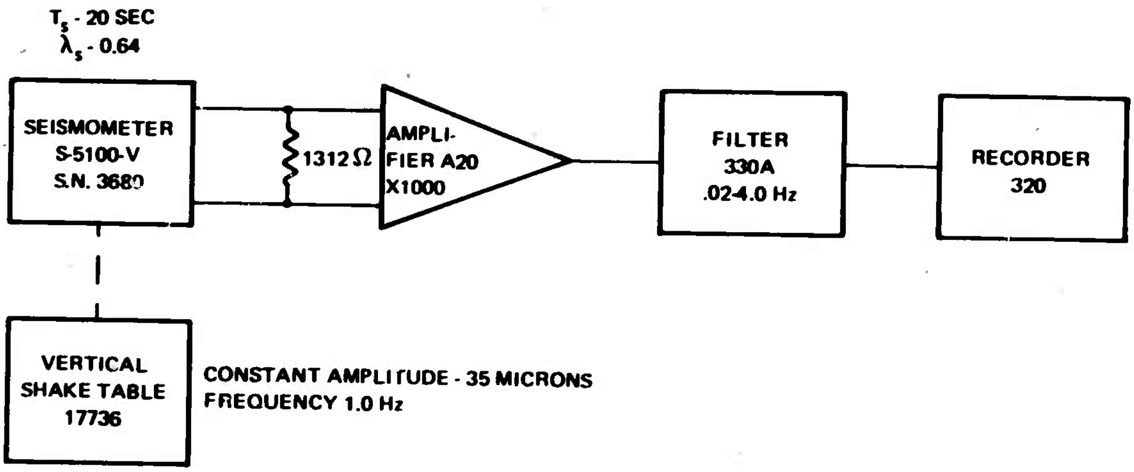
The air damping, as determined from the rate of decay of free oscillation, was $\lambda = 0.0137$.

3.6 SPECIFIED PARAMETERS

Table 1 lists the values of seismometer parameters specified in the manufacturer's instruction manual and compares them with the values measured on the unit tested.

Table 1. Comparison of published and measured parameters for Vertical Long-Period Seismometer, Sprengnether Model S-5100V, Serial No. 3680

Parameter	Published value	Measured value
Spurious resonances		
Helical spring (rotational)	-	2 Hz
Helical spring (fundamental)	22 Hz	18.4 Hz
Boom (torsional)	25 Hz	21.3 Hz
Unknown source	60 Hz	60 Hz
Unknown source	100 Hz	100 Hz
Signal coil		
Generator constant (#1)	89 V-sec/m	89.5 V-sec/m
Generator constant (#2)	89 V-sec/m	89.2 V-sec/m
Resistance (#1)	500 ohms	484 ohms
Resistance (#2)	500 ohms	476 ohms
Critical damping (#1)	-	1160 ohms @ T = 20 sec
Critical damping (#2)	-	1152 ohms @ T = 20 sec
Calibration coil		
Motor constant	5.0 N/A	5.22 N/A
Resistance	68 ohms	64.4 ohms



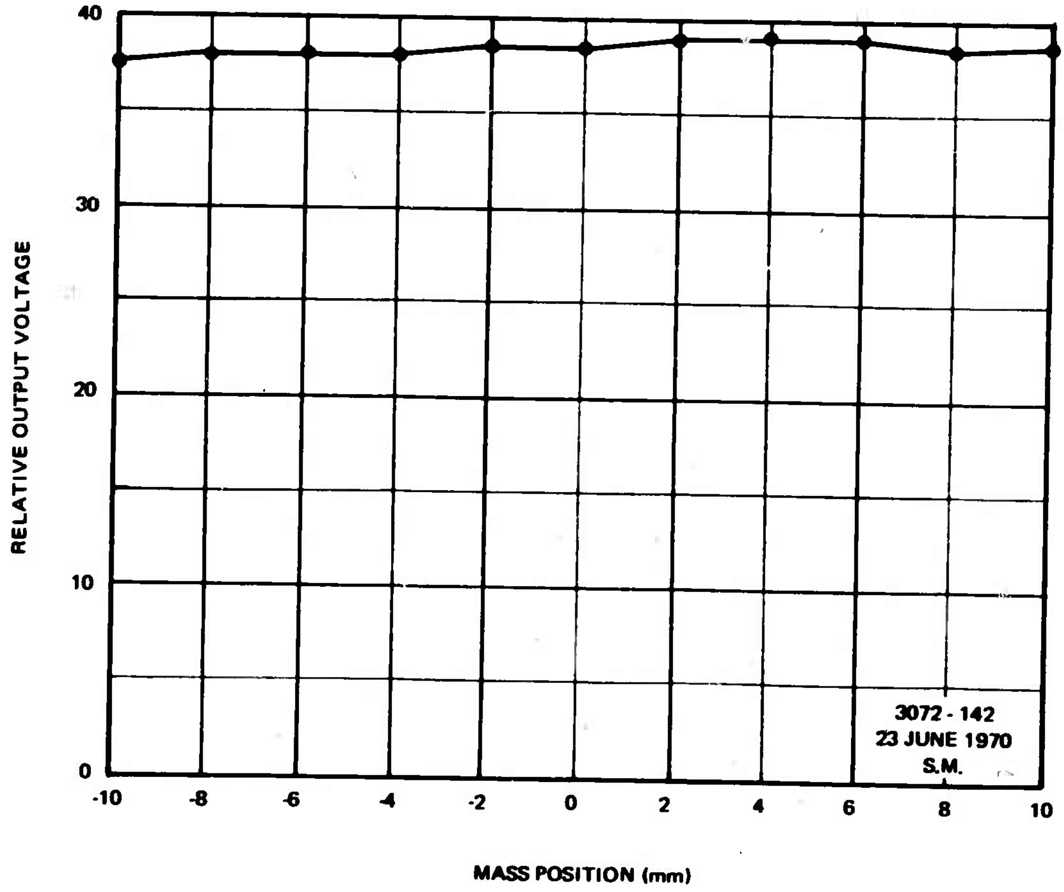
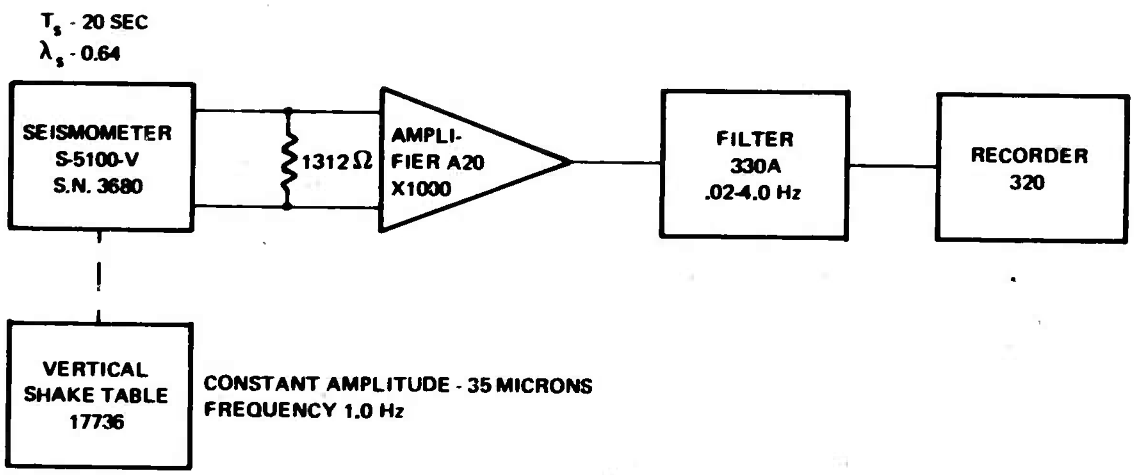


Figure 13. Data coil No. 1 output vs mass position for 1 Hz constant amplitude excitation

G 6048



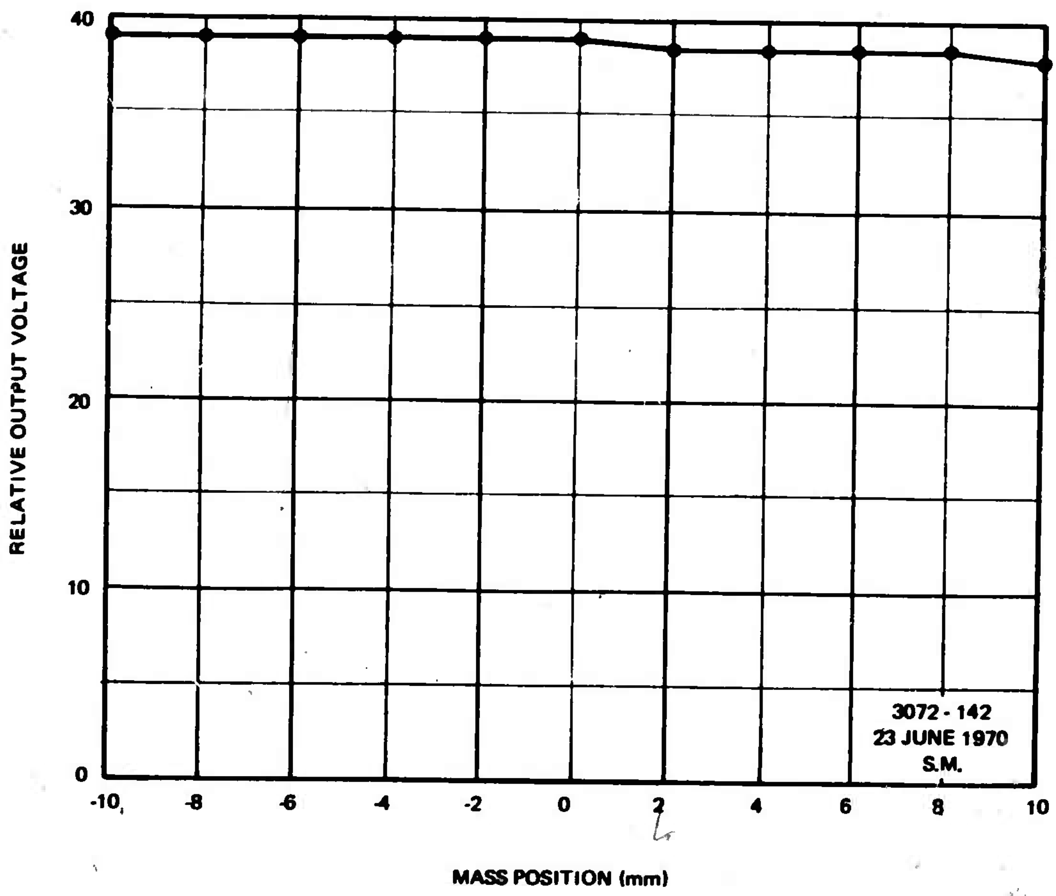
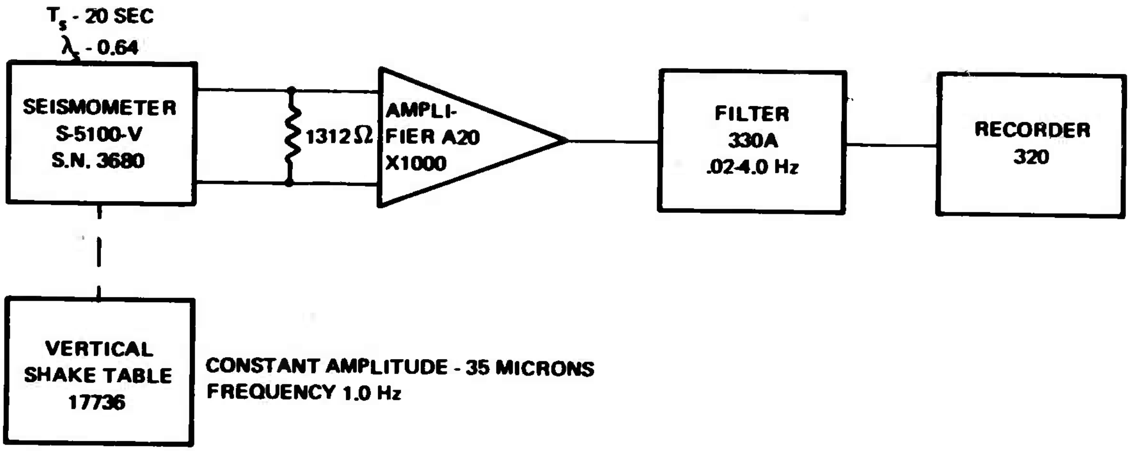


Figure 14. Data coil No. 2 output vs mass position for 1 Hz constant amplitude excitation

G 6049



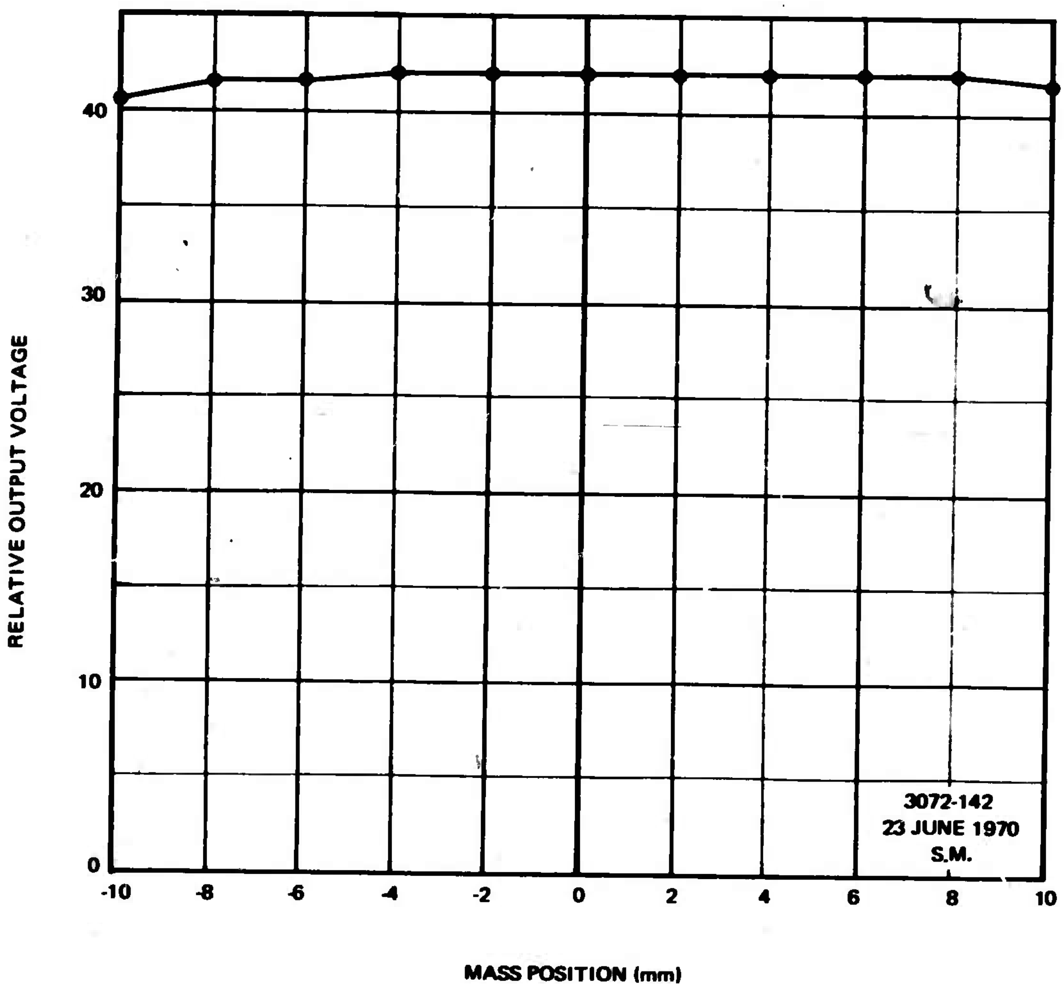


Figure 15. Series data coil output vs mass position for 1 Hz constant amplitude excitation

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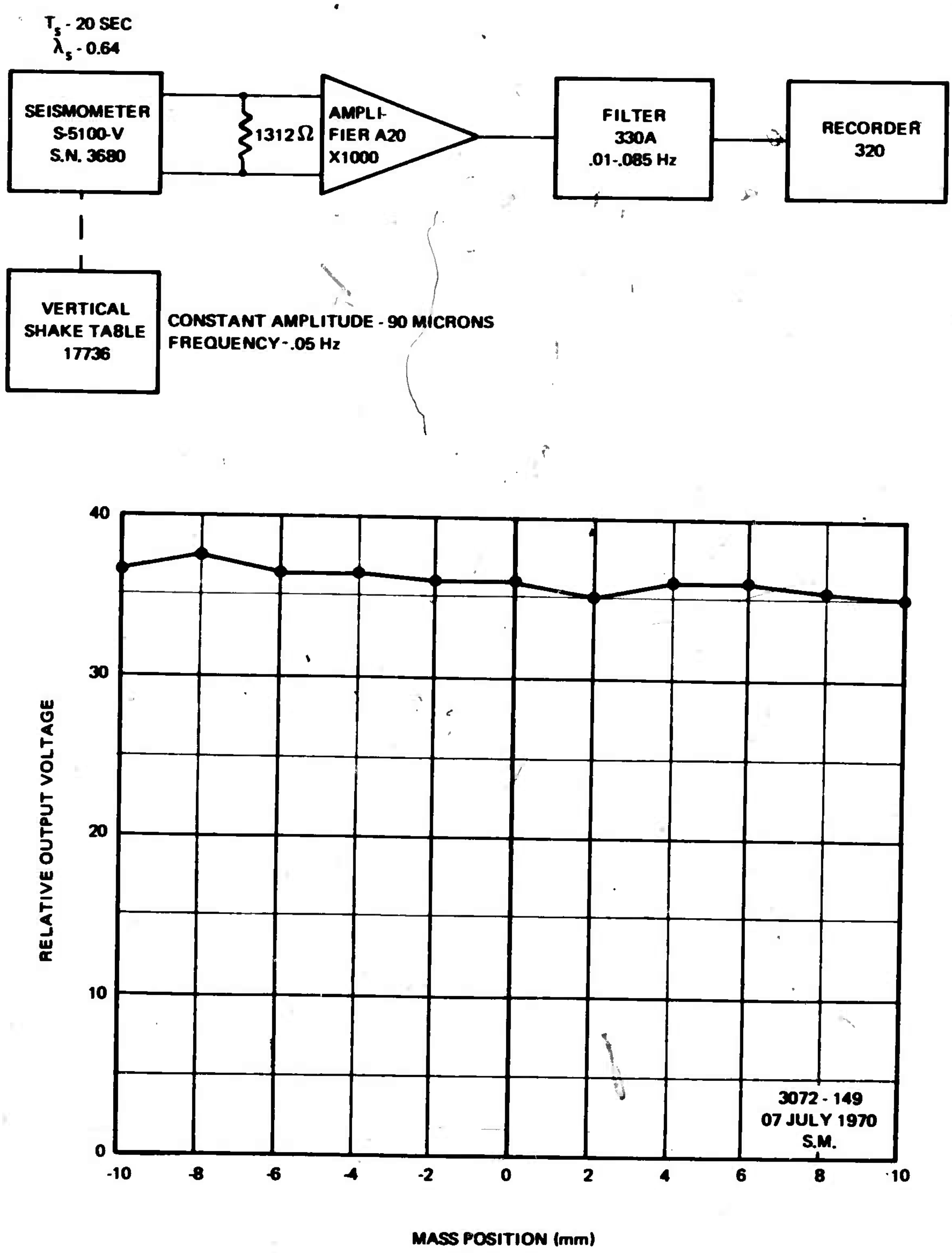
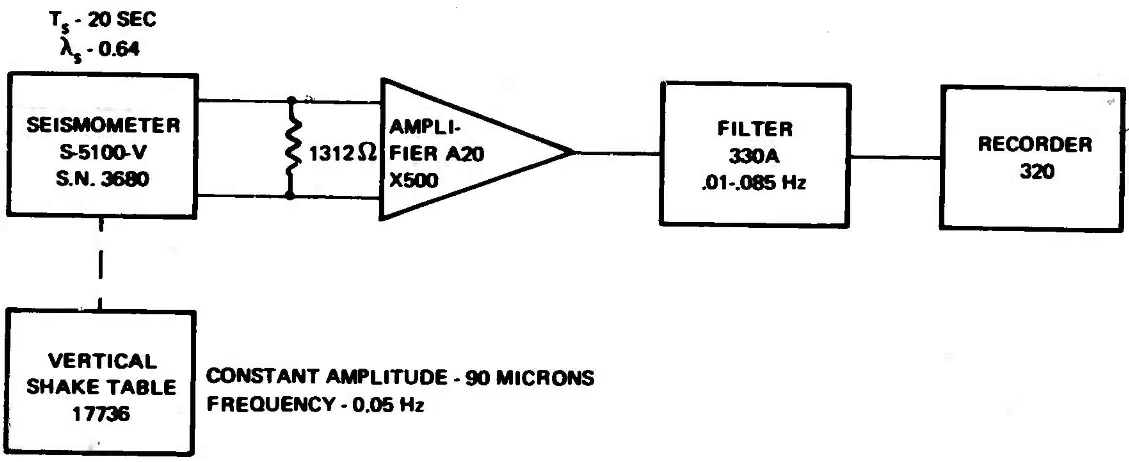


Figure 16. Data coil No. 1 output vs mass position for 0.05 Hz constant amplitude excitation

G 6051



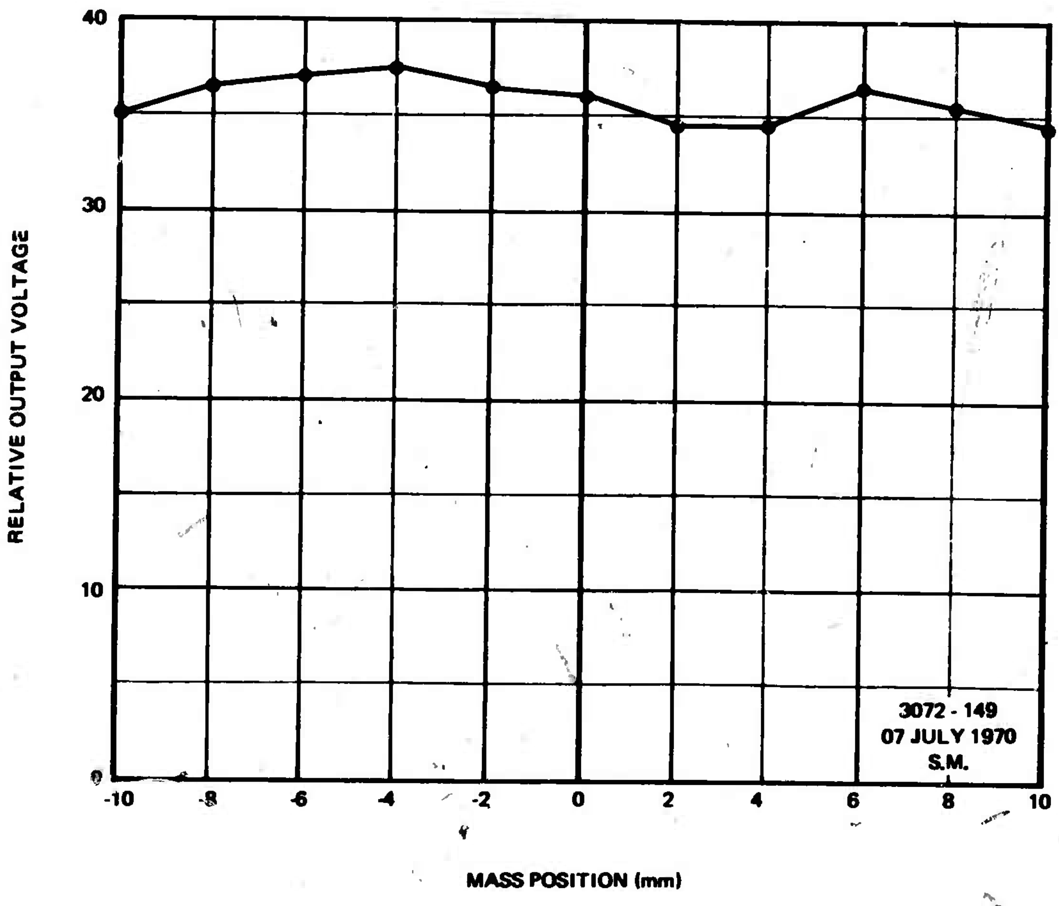
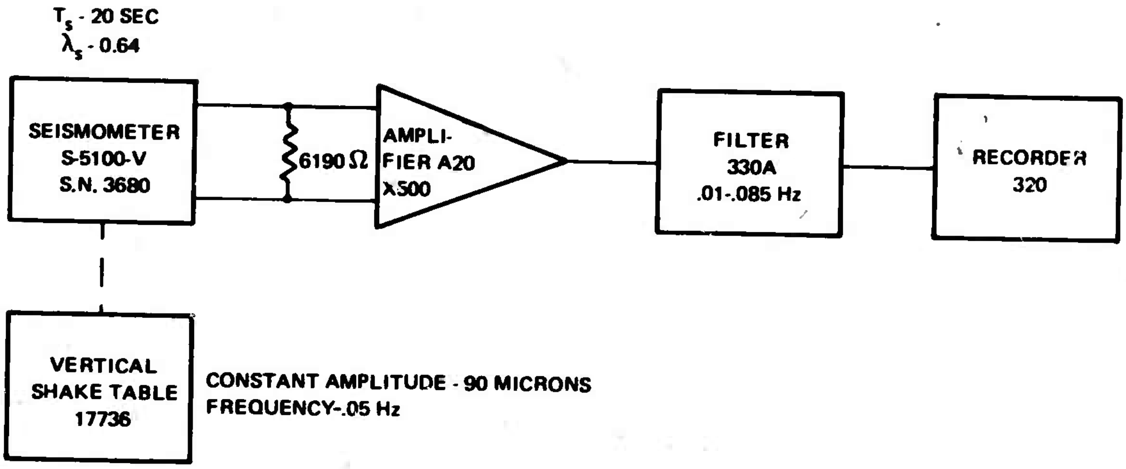


Figure 17. Data coil No. 2 output vs mass position for 0.05 Hz constant amplitude excitation

G 6052



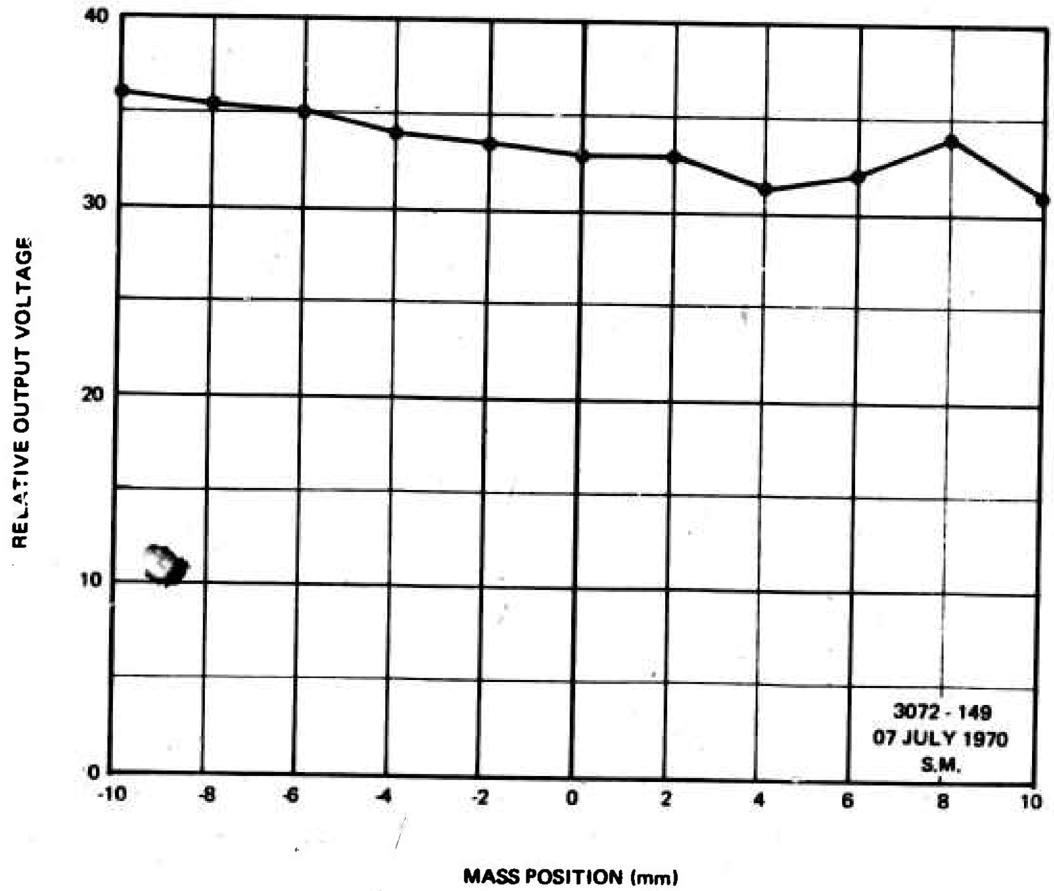


Figure 18. Series data coil output vs mass position for 0.05 Hz constant amplitude excitation

G 6053

3.7 CAPACITANCE TRANSDUCER

Performance characteristics of the Capacitance Transducer, Sprengnether Model VCT-201, and its associated electronic circuits were measured with the capacitance transducer mounted on the S-5100V seismometer.

During initial setup and subsequent adjustment of the detector circuit, it was found that control settings were extremely critical. In particular, the controls used to balance the detector for zero output were so sensitive that it was impractical to attempt circuit balance at magnifications greater than several thousand. Furthermore, detector balance was affected by body capacitance. That is, detector balance changed when the operator's hand was removed from the vicinity of the circuit, even though all circuits were grounded in accordance with radio frequency grounding techniques and an insulated-shaft screwdriver was used to engage the control shafts. For these reasons, it was necessary, during noise tests, to zero the recorded trace using balance controls in circuits that followed the detector.

Linearity of the capacitance transducer and its electronics was determined by visual observations, using the scale on the seismometer to determine mass position and a Voltmeter, Dynamics Model 502, to measure detector output voltage. The relationship between mass position and output voltage is shown in figure 19. Note that the capacitance transducer system deviates less than 1 percent from a straight line for mass positions from -5 to +5 mm, but becomes increasingly non-linear beyond these positions, and deviates nearly 20 percent from a straight line at -10 mm and +10 mm.

Noise measurements of the capacitance transducer system were undertaken using a circuit with the configuration and frequency response shown in figure 20. The seismometer was left on the pier in the underground vault where its performance with a phototube amplifier had been tested, and the detector circuits were connected to it using cables furnished with the instrumentation. To keep high impedance cables short, the 425-A amplifier was installed in the vault, but the recorder was placed in the laboratory approximately 20 feet from the 425-A amplifier. System noise was high, and was found greatest in three spectral areas. The drift, or extremely long-period noise was greatest and caused full scale trace deflections (equivalent to 3 μ of mass motion) to occur in times as short as one hour. Superimposed on the drift was a noise of 70-90 sec period and an amplitude equal to a ground motion of 6-10 μ. This noise occurred at random times and was generally one-half to one cycle long. A third band of noise was observed to occur at a period of 2-3 sec with an amplitude of 150 mμ. Though not sinusoidal, or even periodic, it occurred most often of the noises observed and with most nearly a constant amplitude.

Additional noise tests were run with the seismometer and all circuitry in the laboratory. Data showed that the capacitance transducer circuits and cables were highly temperature sensitive, and that temperature changes of one to two degrees F would unbalance circuits enough to cause off-scale drifts. From attempts to insulate first the detector circuit, and then the detector cables, it was found that both are very sensitive to temperature changes.

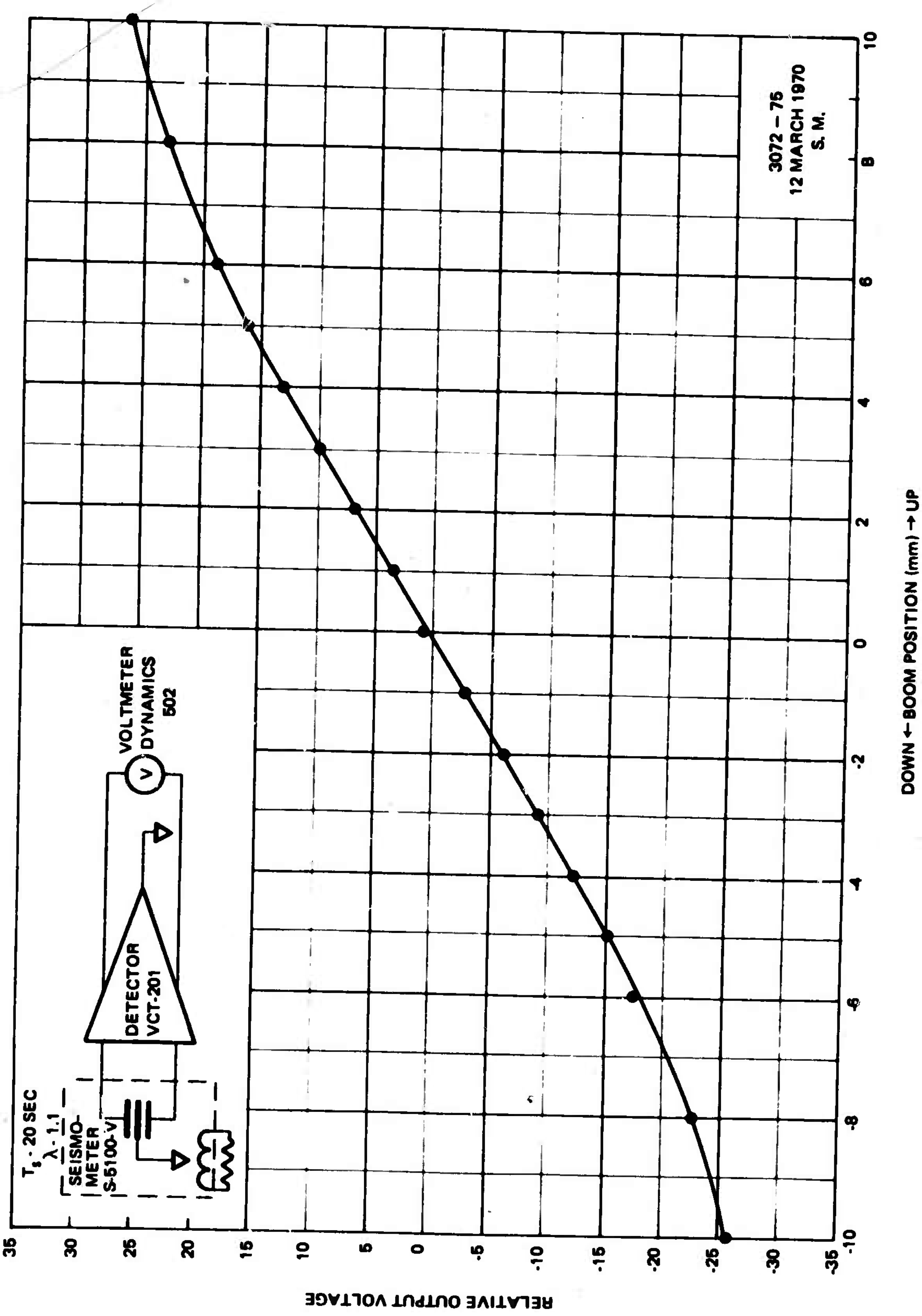


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Figure 19. Linearity of capacitive transducer and detector, Sprengnether Models VCT-203 and VCT-201

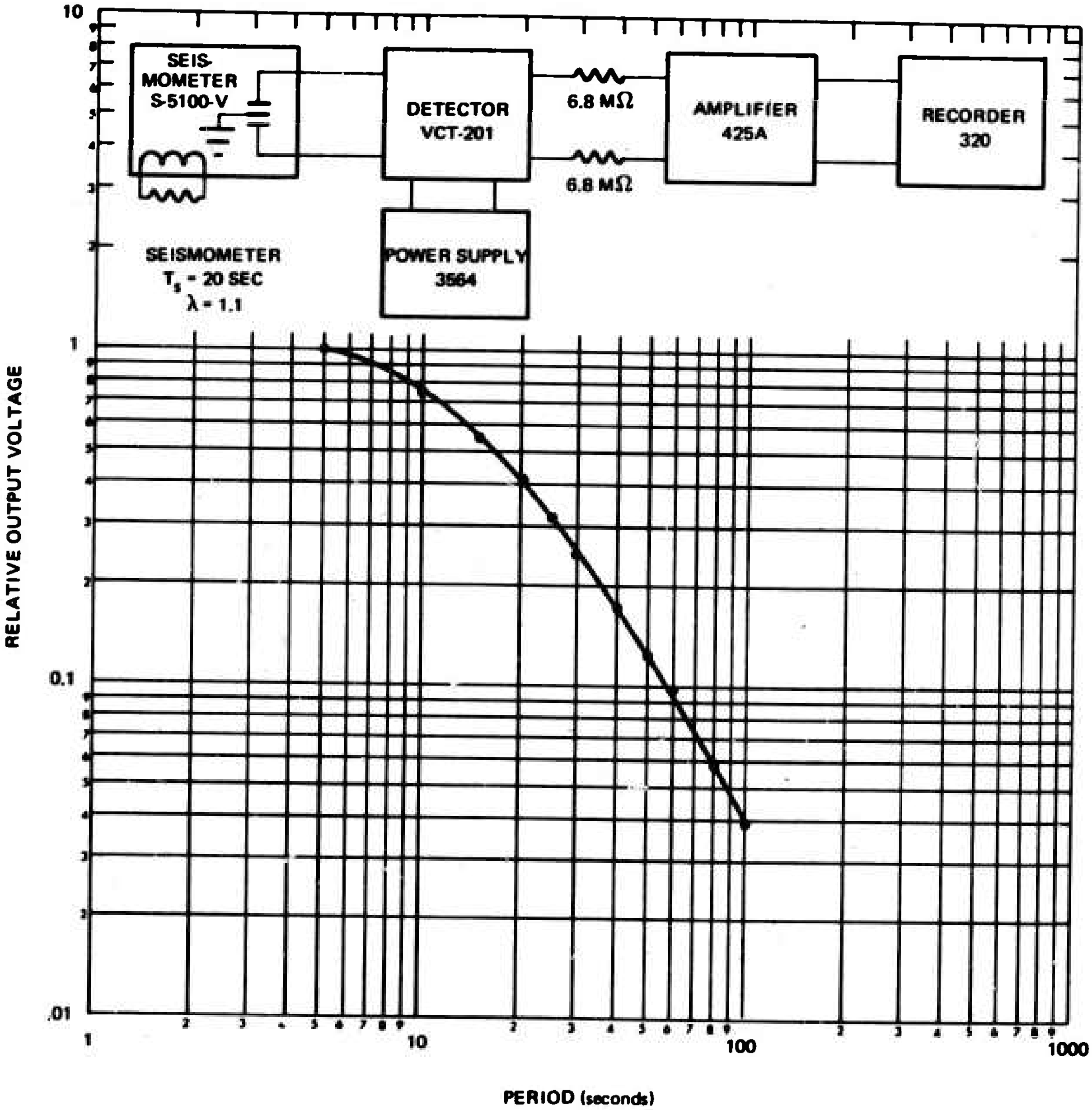

Figure 20. Frequency response of long-period seismograph with capacitive transducer

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4. OPERATIONAL TESTS

4.1 DESCRIPTION OF SYSTEM

For more than a year, a high-magnification, two-channel, extended response vertical LP seismograph has been operated routinely at our Garland laboratory. Earth motions are sensed by one Model 7505A seismometer set upon the pier in our underground concrete vault and amplified by one galvanometer-phototube amplifier. The output of this amplifier is split into two channels which are identified as Z25-2 and Z40-2, and which are conditioned by separate electronic filters to provide different channel response characteristics. The seismometer has an integral pressure-tight cover, and is not mounted in any other pressure-tight tank or vault. The seismometer and all electrical connections to the seismometer signal circuits are insulated with Fiberglas batts.

The Z25-2 and Z40-2 seismograph channels, whose performance characteristics were well-known, were used as controls for the operational tests of the Model S-5100V seismometer. Their routine operation was continued throughout the operational tests.

The Model S-5100V seismometer was installed and operationally tested on the same pier as the Model 7505A seismometer. It was insulated like the 7505A seismometer and a thermistor probe was placed inside its case to sense the temperature there. A phototube amplifier and active filter were used to amplify and shape its output. The frequency responses of this seismograph (Z-S), the Z25-2 channel, and the Z40-2 channel are shown in figure 21. Data from all channels were recorded on both Develocorder film and Helicorder paper.

4.2 RESULTS

Sprengnether system noise, recorded with the seismometer mass blocked, was greatest at a period of 70 sec and was equivalent to an earth motion of 10 mμ p-p. During a two-week operational test period, the temperature within the seismometer case remained at 78.5 ±0.25°F.

Figures 22 through 24 show typical records made during the operational tests. Note that the high longer-period (above 50 sec) noise limited the usable ZS magnification to less than 1/3 of the Z25-2 and Z40-2 magnifications and obscured the smaller amplitude seismic signals. The large noise amplitude on the SZ records - several times greater than on the Z25-2 and Z40-2 records, the variation in noise amplitude, and the presence of the longer-period waves suggested that most of this noise might be caused by atmospheric pressure fluctuations producing buoyant forces upon the inertial mass and moving it. To verify this, the 7505A seismometer case was unsealed and a large increase in the background noise on the Z25-2 and Z40-2 seismograms was noted.

The mass position of the S-5100V seismometer remained within the ±10 mm operating range without requiring adjustment during the entire operational test period. Its period was set to 26.0 sec and did not change discernibly during the same test period. At longer natural periods, the mass position was less stable. When tested at T_s = 39 sec, the mass moved from center position to one stop in 12 hours. No attempt was made to determine whether the mass position would become stable at this period or how long it would take to stabilize.

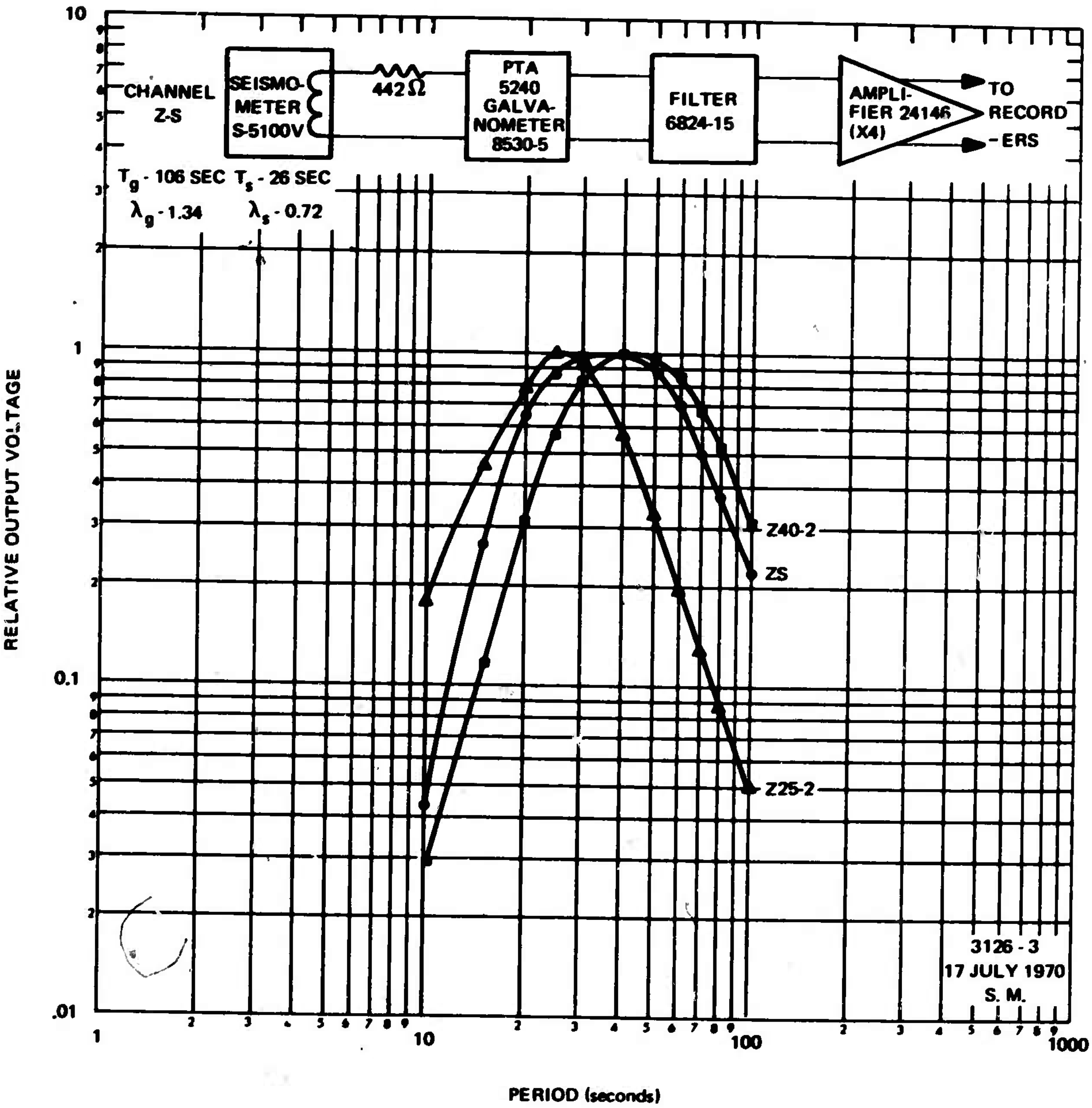

Figure 21. Frequency responses of seismographs used during operational tests

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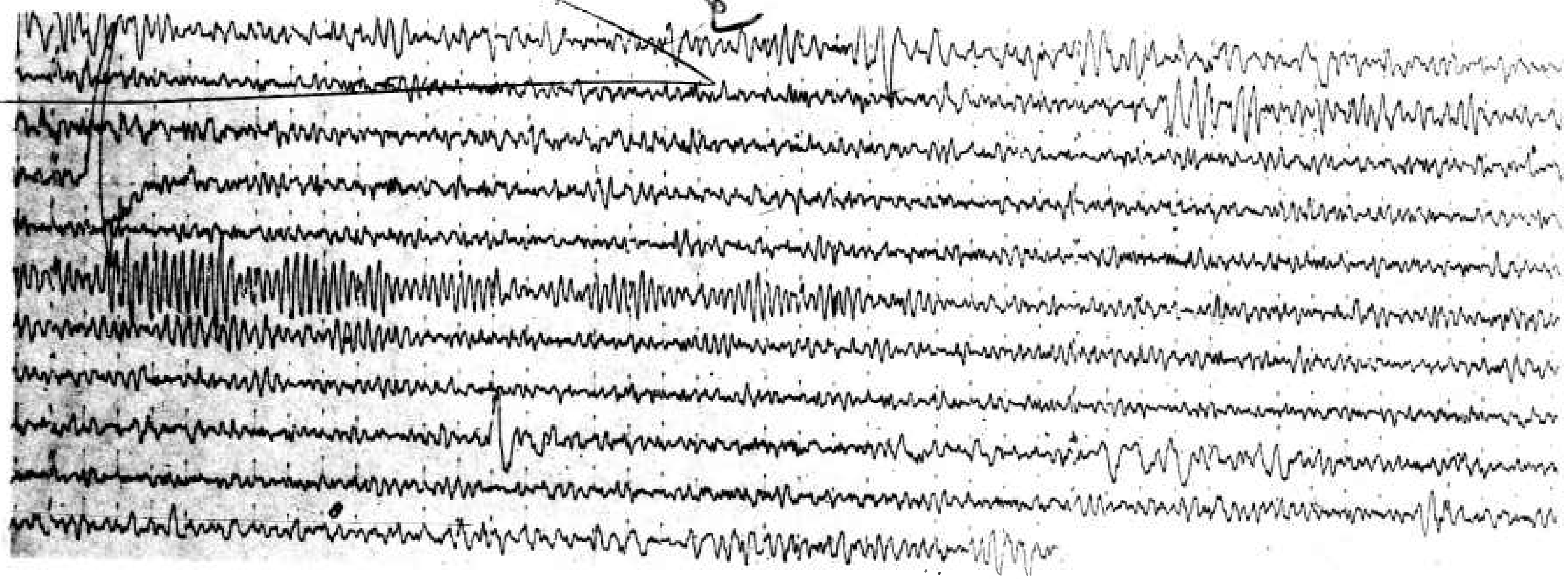
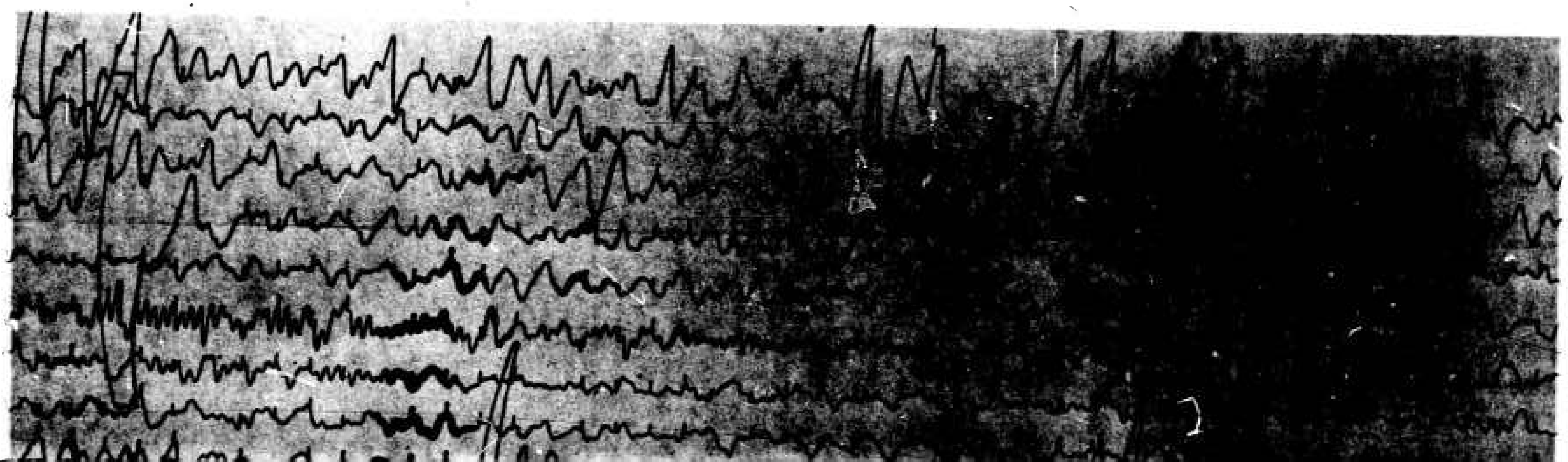
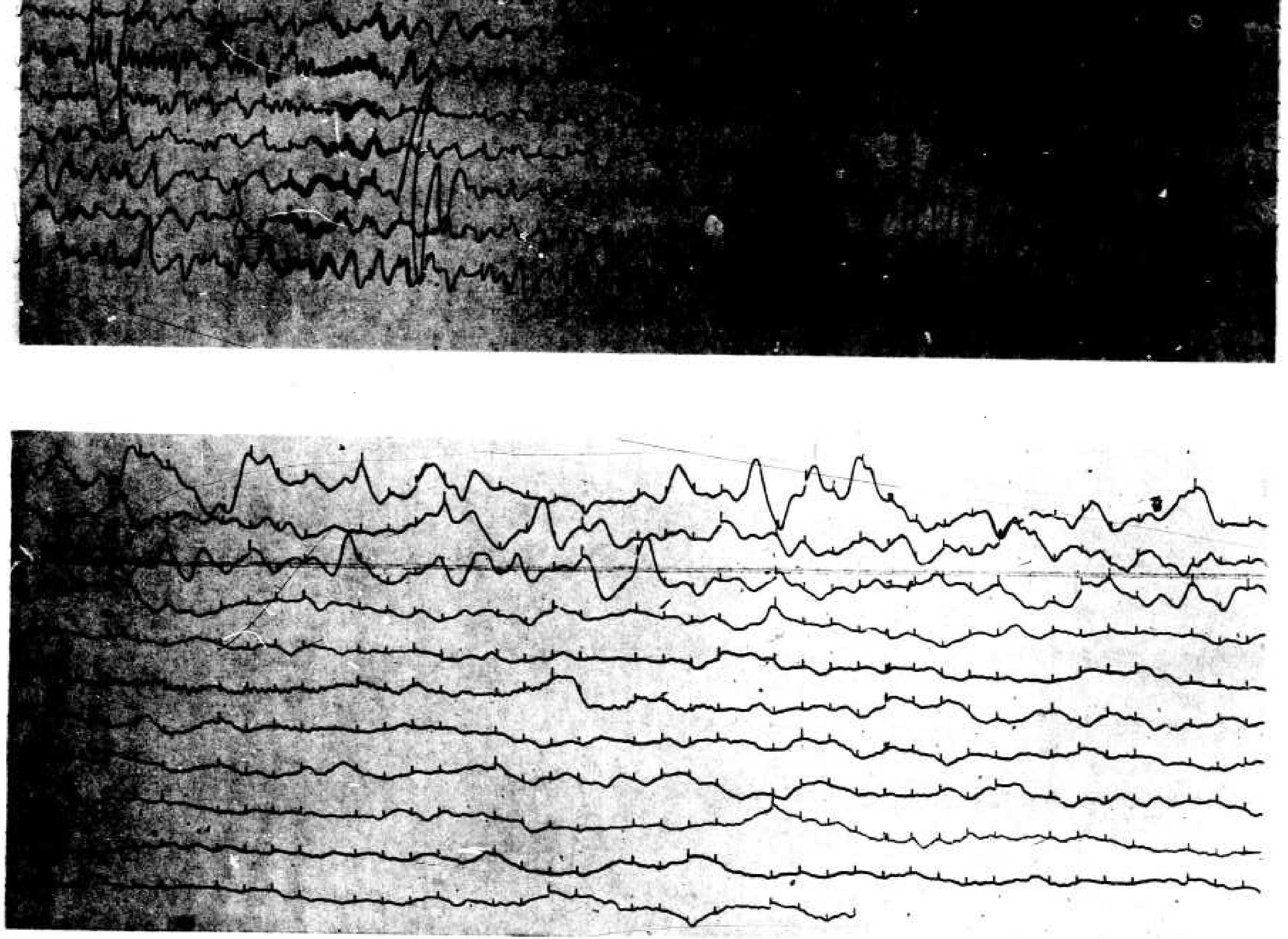
Z25-2
M = 80K
@ 25 SEC



Z40-2
M = 100K
@ 50 SEC



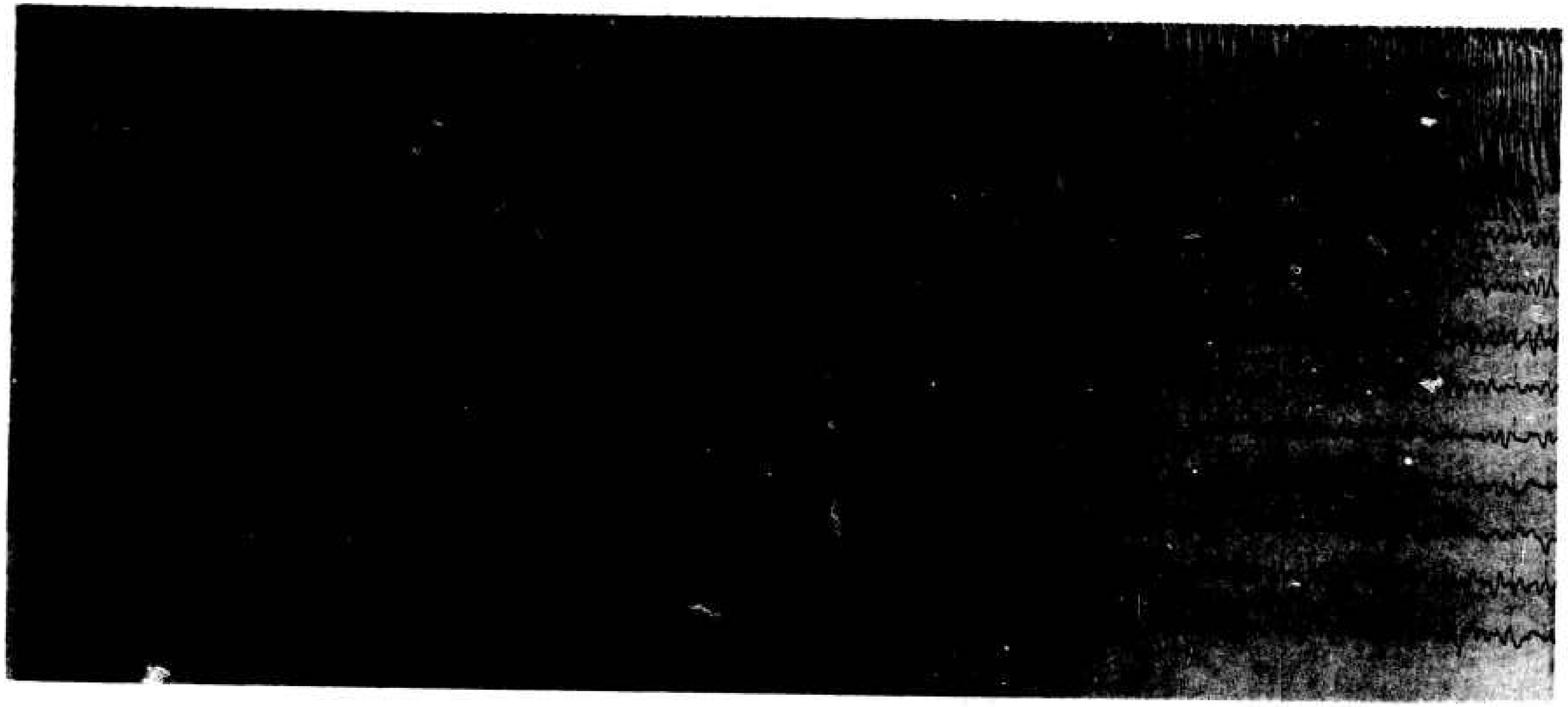


Z-S
M = 30K
@ 40 SEC

GARLAND, TEXAS
21 JULY 1970
RUN 202

Figure 22. Long period seismograms comparing performance of Z25-2, Z40-2, and Z-S channels during period when atmospheric pressure variations were small. Epicenters of recorded events are unknown.

Z25-2
M = 75K
@ 25 SEC



Z40-2
M = 80K
@ 50 SEC

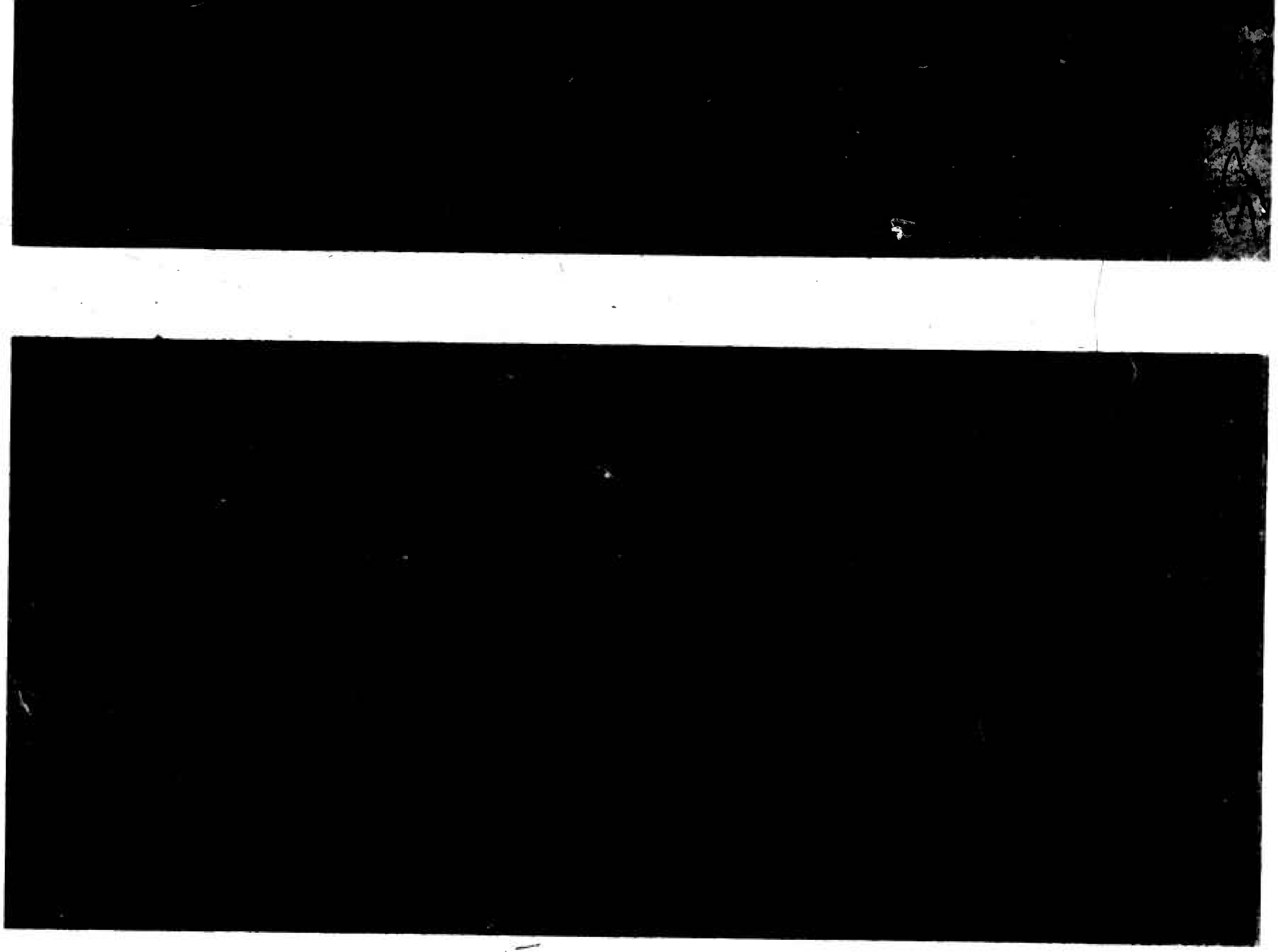
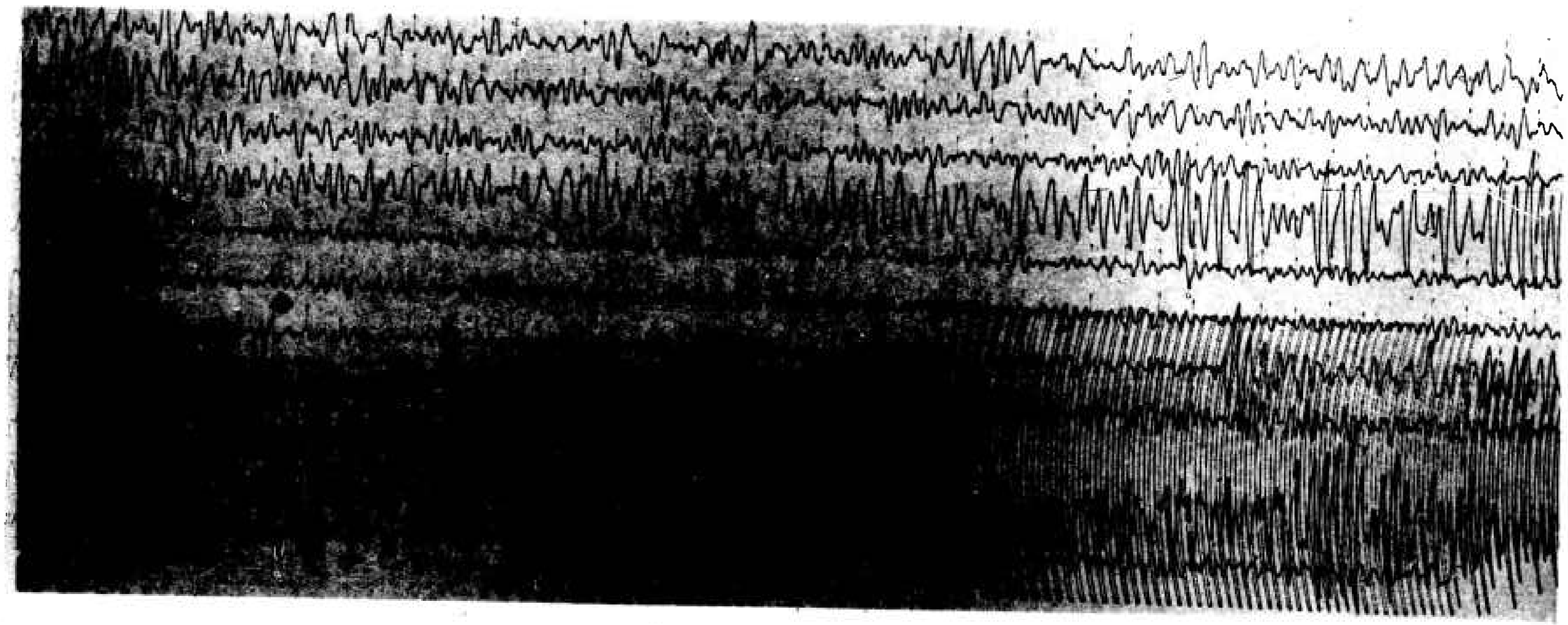
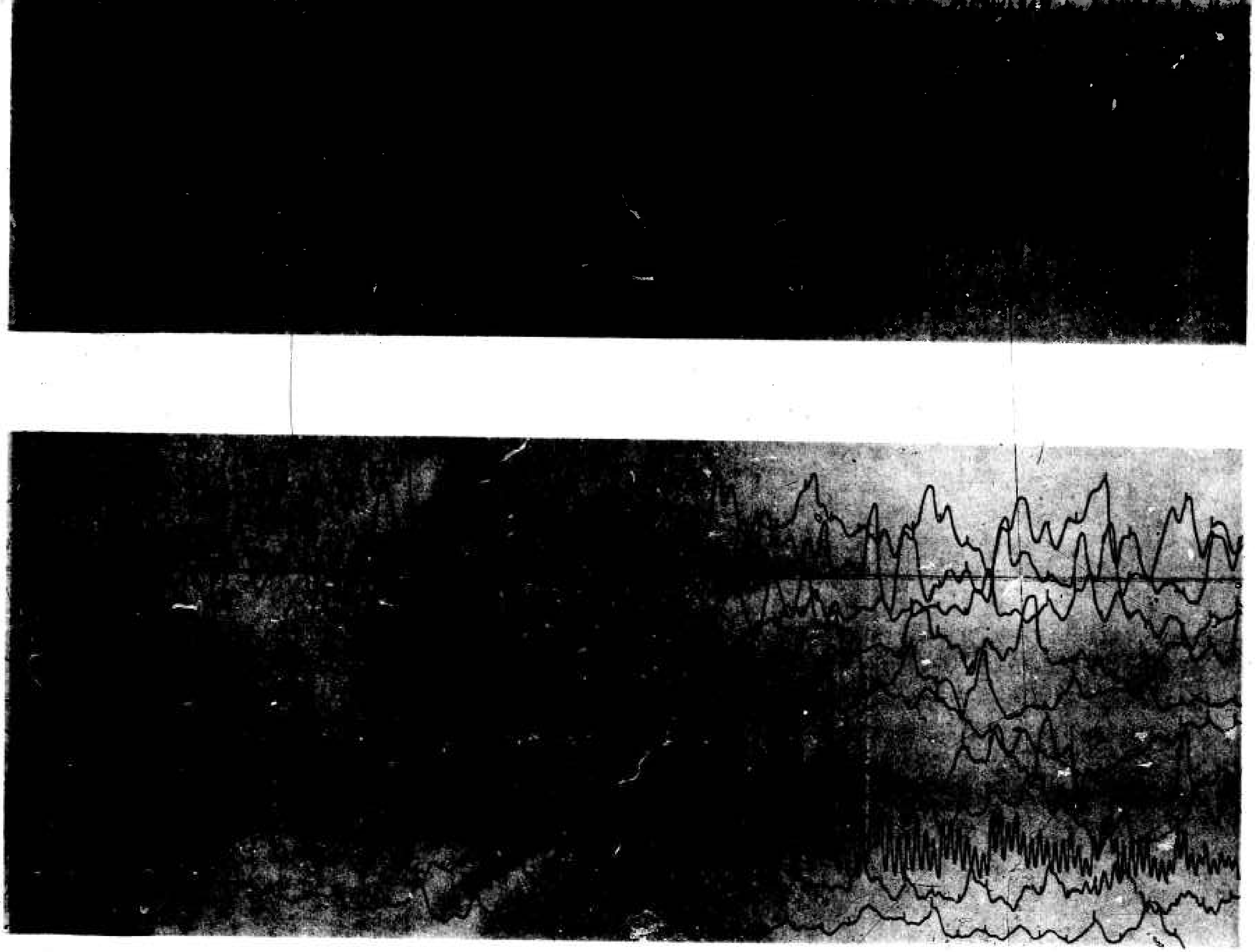


Figure 23. Long period seismograms comparing performance of Z25-2, Z40-2, and Z-S channels during approach of weather front, when atmospheric pressure variations are increasing. Epicenters of events are unknown.

Z25-2
M = 85K
@ 25 SEC



Z40-2
M = 95K
@ 50 SEC



Z-S
M - 30K
@ 40 SEC

GARLAND, TEXAS
20 JULY 1970
RUN 201

Figure 24. Long period seismograms comparing performance of Z25-2, Z40-2 and Z-S channels during windy time period. Epicenters of events are unknown.

5. DISCUSSION AND CONCLUSIONS

The S-5100V seismometer appears to have good mechanical design and construction. It was easy to assemble and adjust, and its parts fit together accurately. The one exception noted was that the threads in the suspension clamp ring are marginally weak and are prone to fail. One of the two units supplied with the seismometer failed during assembly.

The S-5100V seismometer was mechanically stable throughout all tests. Its seismograms displayed none of the characteristic pulses which are associated with the relaxation of mechanical stresses in seismometers.

Performance of the S-5100V seismometer is strongly dependent upon its operating temperature. Mass position varies with temperature at a rate of more than 3 mm per °F. A change of 7°F swings the mass from one extreme position (-10 mm) to the other (+10 mm) when the natural period is 20 sec. At the extremeties of mass position, the seismometer operation will cease; throughout the intermediate mass positions, the instrument natural period (and hence damping and sensitivity) will vary to a degree that depends upon two factors: 1) the natural period to which the seismometer was set, and 2) the linearity of the period vs mass position characteristic for the instrument. Therefore, the S-5100V seismometer must be installed so that it will operate in an environment whose temperature is constant to ±3°F and which will vary at frequencies outside the passband of interest. Wider temperature variations can be tolerated if remote mass positioning equipment is used.

Buoyancy of the S-5100V seismometer inertial mass causes the instrument to respond to atmospheric pressure changes and limits the useful magnification of a seismograph using this instrument to low values. For all high-magnification operation, the S-5100V seismometer must be installed in a sealed container built to attenuate atmospheric pressure changes in the passband of interest. A suitable sealed container was not available for these tests.

The capacitance transducer and detector system that was tested has several features which make it unsuitable for use in high-magnification, long-period seismographs. First, its circuits are provided with very coarse controls that are extremely difficult to adjust. Second, their balance is affected by stray capacitance to surrounding objects. The withdrawal of an operator from the proximity of the circuit will change its tuning. Third, its circuit balance is highly dependent upon temperature. Small temperature changes will cause circuit unbalances which will appear as noise. This appears to be the mechanism which produced the observed full scale drifts and 70-90 sec noise. Noise at shorter periods (150 mμ at 2-3 sec) appears to be caused by the detector circuit components.

It is concluded that the S-5100V seismometer, when equipped with remote mass position and period controls, is well suited for use as a component in a high-sensitivity, long-period seismograph provided that it is installed in an environment well isolated from pressure and temperature change. The capacitance transducer and detector system, which cannot be balanced remotely, is more limited in its application, even when installed in a like environment.

6. ACKNOWLEDGEMENTS

The author expresses his appreciation to Dr. Mark Landisman, of the University of Texas at Dallas, for making available the Sprengnether equipment used in this work, and to Mr. S. Montoya, who spent many hours installing instrumentation, adjusting parameters, and collecting data for this evaluation.

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Teledyne Geotech 3401 Shiloh Road, Garland, Texas	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

Evaluation of the Vertical Long-Period Seismometer, Sprengnether Model S-5100V

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Special evaluation

5. AUTHOR(S) (First name, middle initial, last name)

Martin G. Gudzin

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
14 September 1970	37	

8a. CONTRACT OR GRANT NO. F33657-70-C-0733 b. PROJECT NO. Project VT/0704 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) Technical Report No. 70-30 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
None.	Air Force Technical Applications Center

13. ABSTRACT

The Sprengnether Model S-5100V seismometer, equipped with both electromagnetic and capacitive transducers, was assembled and tested in the laboratory and in a vault. Data concerning its measured performance characteristics were collected and evaluated.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Long-period seismometer Long-period seismograph						